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---TECHNICAL REPORT---

THE NATION'S LABORATORY FOR ADVANCED AUTOMOTIVE TECHNOLOGY

No. 13514



WINNER OF THE 1995 PRESIDENTIAL AWARD FOR QUALITY

ENGINE INTAKE AIR DUST DETECTOR (U)

(PHASE II)

CONTRACT NUMBER DAAE07-89-C-R011

NOVEMBER 1990

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13. ABSTRACT (Maximum 200 words) This report describes a program to develop criteria for an on-vehicle dust detector to monitor engine induction air quality and provide a warning when unacceptable levels of dust are present, and to seek out and evaluate existing or developing technologies for such a detector through parametric analyses and bench and full-scale laboratory testing. Standard air filter tests were conducted to characterize the degree of protection afforded by military air cleaner systems under normal and abnormal filter operation. Primary parameters of interest were downstream particle size and concentration level as a function of filter dust loading and operating mode. Consideration was also given to the level of dust protection required by engines, although this turned out to be a minor factor in specifying the dust detector's operating requirements. Instead, it was found that performance of the clean filter element was the controlling factor as far the dust detector's triggering criteria were concerned because a clean filter inherently passes a large number of particles early in its loading history, even when operating properly, and these particles must be accommodated by the detector without triggering. Because it was desirable to obtain a single dust detector for use on all military tactical and combat vehicles, a broad-based, "go/no-go" triggering criteria was developed to include a margin of safety against false triggering under worst case conditions for a normally operating filter. Three parameters were chosen: particle size, concentration, and response time. No commercial off-the-shelf dust detectors were found for the intended application; however, several units and technologies were identified as having potential for meeting both the particle sensing and stringent vehicle interfacing requirements needed for military vehicles. In order to investigate and quantify the performance of these units (and technologies), trade-off studies were conducted to rank relative performance, to measure performance against certain minimum requirements, and to demonstrate proof-of-concept and infer overall system potential for vehicle integration. These studies were supported by laboratory bench testing, and in some cases, full-scale laboratory testing on a 5-ton truck mock-up. The implications of vehicle interfacing showed that overall dust detector performance will be very sensitive to duct configuration and sensor placement, and therefore, these parameters must be carefully considered for each class of vehicles. Finally, interpretation of the dust detector specification must take into account the type of technology employed, particularly with respect to concentration and response time triggering criteria. Nonetheless, sensor performance can still be compared against a set of "must trigger" and "must not trigger" distributions.				
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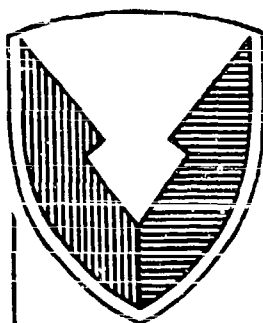
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1.0. INTRODUCTION

This final technical report, prepared by TSI Inc. for the U.S. Army Tank-Automotive Command (TACOM) under Contract DAAE07-89-C-R011, describes Phase II in the development and testing of a dust detector. A dust detector is a sensor which continually monitors the performance of a vehicle's aircleaner system. It measures the level of dust getting past the air filter and immediately alerts the driver if this level gets too high. Currently, there is no way to know if an air filter fails or is improperly installed until the engine is damaged by excessive dust levels. The dust detector will give added protection to an engine just like an oil light does.

2.0. OBJECTIVE

Prior to this contract, a phase I contract (DAAE07-87-C-R055) was completed under which a bench-top prototype was developed. The purpose of this phase-II contract is to improve on the phase-I prototype. The instrument is to be ruggedized so it can operate in the harsh vehicle surroundings. Environmental testing is to be conducted on the instrument. The dust detector is to be made ready to install and operate on actual vehicles. Another objective is to simplify the design to reduce the final production cost. Ten units are to be delivered to TACOM at the end of the contract.

3.0. CONCLUSIONS

The design was greatly simplified from the phase-I prototype, which will reduce the final production cost. The instrument was ruggedized to withstand the vehicle environment. The instrument successfully passed all the environmental testing. Field testing was successfully completed by installing and operating a dust detector on a vehicle in desert conditions. Ten units were delivered to TACOM at the end of the contract. These will be installed on various Army vehicles for further evaluation.

4.0. RECOMMENDATIONS

The dust detector provides an excellent solution to the problem of engines being damaged by faulty air filters. It has proven that it can make the necessary measurement and can withstand the vehicle environment. Installation is simple, and regular maintenance is not needed. The simple design will make low-cost, high-volume production possible, once additional manufacturing engineering is done. Therefore, it would be a very cost-effective addition to vehicles with expensive engines or vehicles frequently in dusty conditions.

5.0. DISCUSSION

5.1. Background

5.1.1. Need for a Dust Detector. Many army vehicle engines have been damaged by ingesting high levels of airborne dust. This happens when a leak develops in the air filter media, seal or piping. Leaks also occur when a filter element is replaced improperly. In dusty areas, filter elements are replaced often, which increases the risk of improper installation. Replacing or rebuilding a damaged engine on larger vehicles can be very costly. A sensor which could warn the driver of a faulty air cleaner would help prevent engines from being damaged. A dust detector on every vehicle would save money in the long run, if it were appropriately priced. It would also decrease vehicle downtime.

5.1.2. Design Requirements. A successful dust sensor must meet several requirements. It must be able to accurately measure the concentration of airborne dust. It must detect dust concentration increases quickly, so the driver can be alerted before the engine is damaged. The instrument must be rugged enough to operate in the harsh vehicle environment. This includes hot temperatures in the engine environment and the shock and vibration of the vehicle. It must be small enough to be easily installed on the vehicle. Maintenance needs must be minimal. Also, it must have a simple design so it can be produced at a reasonable cost.

5.1.3. Limitations of Current Technology. Before the development of the dust detector, there was no practical vehicle dust sensor available. There are many instruments which can measure the concentration of airborne dust, but none were suited for this application. The main limitations are their lack of ruggedness and high cost. Most of these instruments are designed for laboratory use. They are either too large, complex, fragile, or costly. Some require frequent operator input and recalibration.

5.1.4. Phase I Development. The phase I prototype was developed under contract DAAE07-87-C-R055. This was a bench top version which proved the measurement could be accurately made. It showed the instrument could be made small enough and that the design would be simple. However, environmental testing was not done, since the instrument was not ruggedized. It was not ready to be installed on a vehicle.

5.2. Theory of Operation

5.2.1. Optical Particle Detection. The dust detector belongs to the class of particle detection instruments known as optical particle detectors. The airborne particles are detected by their interaction with light. Furthermore, the dust detector is a single particle detector, in that it can detect individual particles and not just a cloud of particles.

5.2.2. Probe. The dust detector has two main parts. These are the probe which actually detects particles, and the electronics box which processes the information. The probe is mounted directly in the engine's air-intake pipe. The basic probe design is shown in figure 5-1. It has two optical fibers going from the electronics box to a metal probe head. Light is sent down one of the fibers to the probe. The light crosses an air gap in the probe head. The light then returns to the electronics box by the other optical fiber. When a particle passes through the air gap in the probe head, it interacts with the light there, so it can be detected. This probe design has the advantage of being small, simple, and easy to build. It can be mounted directly in the air flow but offers minimal obstruction to the flow. It is rugged because it has no moving parts and no electronic parts.

5.2.3. Concentration Measurement. The probe allows individual particles to be detected. However the real information of interest is concentration, which is particles per unit volume. The alarm trigger level will be based on concentration. The signal processing electronics converts the particles counted to concentration. This can be done, because the cross-sectional area of the probe's air gap is known. This allows particles counted to be directly related to concentration. The dust detector actually measures the concentration of particles above a certain diameter such as 7 micron (7×10^{-6} meter). This size threshold can be adjusted in the electronics to any diameter from 3 micron and up.

5.2.4. Velocity Correction. In order to convert particles counted to concentration, the air velocity past the probe must also be known. If the velocity increases, more particles will pass through the probe's air gap per unit time, even if the concentration stays the

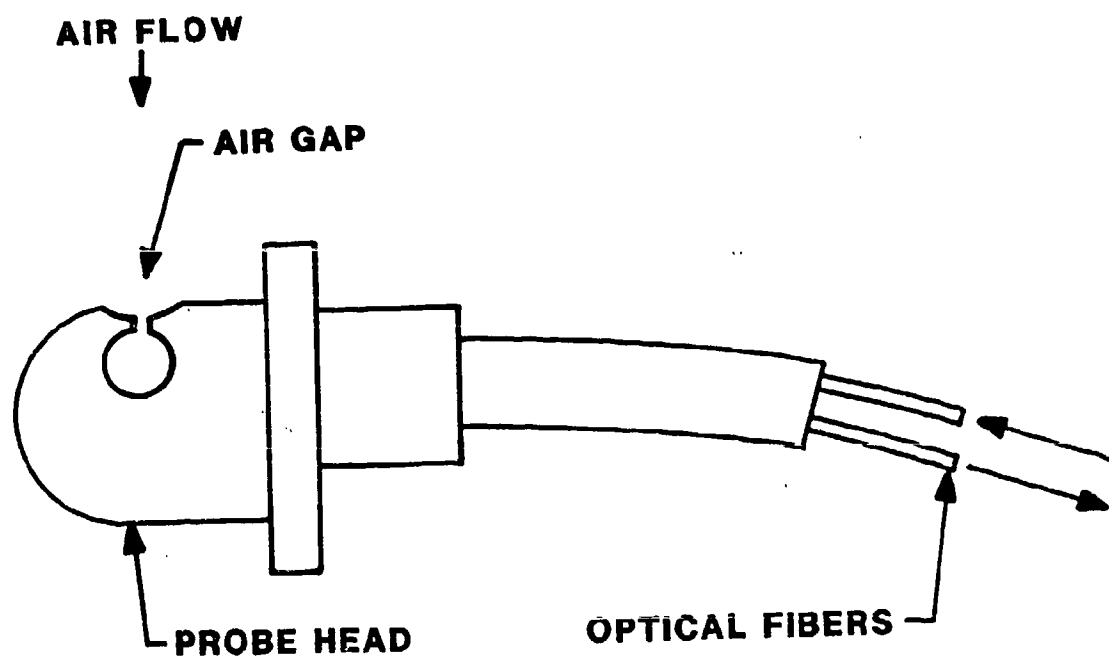


Figure 5-1. Dust Dectector Probe

same. The air velocity in the air intake pipe will change depending on engine RPM. The dust detector is able to factor in this changing velocity. The speed of a particle through the probe's air gap can be measured by the width of its signal as received by the electronics. This allows the air velocity in the duct to be measured and factored in, so only true concentration is calculated.

5.2.5. Filter Efficiency. With a probe installed in the duct after the filter, the dust detector can measure the concentration of dust after the filter. The driver can be alerted if this concentration exceeds a pre-set trigger level. However the dust detector can also measure filter efficiency which is defined as

$$\text{Efficiency} = 100 \times \left(1 - \frac{C_a}{C_b}\right)$$

Where: C_a = Dust concentration after filter
 C_b = Dust concentration before filter

To do this, there must be a second probe installed before the air filter. Both of these probes go to the same electronics box. The concentration is measured at both points, and the efficiency is calculated. If it is below a pre-set trigger level, the driver is alerted. Vehicle air filters are generally better than 99% efficient, which means less than 1% of the dust's total mass gets through the filter. As will be discussed later, efficiency seems to be a much better way to monitor filter performance than just measuring the concentration downstream of the filter.

5.3. Design

5.3.1. Components. The basic components of a dust detector are shown in figure 5-2. The two main parts are the probes and the electronics box. There are two probes, one for before the filter and one for after the filter. The alarm lights are separate, so they can be mounted in a visible place. The electronics are powered from the vehicle's 24 VDC supply, with the ground return being through the case.

5.3.2. Installation. A sample installation is shown in figure 5-3. Installation is straight-forward and simple. The probe heads are inserted into the air-intake pipe through a slot cut in the pipe. They are held in place by screws or hose clamps. The probe cables are routed back to the electronics box, which is mounted in an out-of-the-way place in the driver's compartment. The probe connectors are easily screwed to the electronics box adapters. The alarm light bracket is mounted so the driver can see it. The electronics power wire is connected to the vehicle's power. The ADDENDUM has a copy of the full Operation and Installation Manual, which has all the detail needed to install and operate the dust detector.

5.3.3. Alarms. There are two alarm lights for two independent conditions. The light labeled "DUST LEVEL" indicates the concentration of dust after the filter. This uses only the probe installed after the filter. If the concentration gets above the factory set trigger level, this light comes on to tell the driver high levels of dust are getting into the engine. The light labeled "LEAK" indicates filter efficiency. The leak indication uses both probes to calculate efficiency based on the concentrations before and after the filter. If the efficiency goes below a factory-set trigger level, this light comes on. It tells the driver there is a leak in the air cleaner system that is letting a larger than normal percentage of dust through. The trigger levels for both of these alarms can easily be

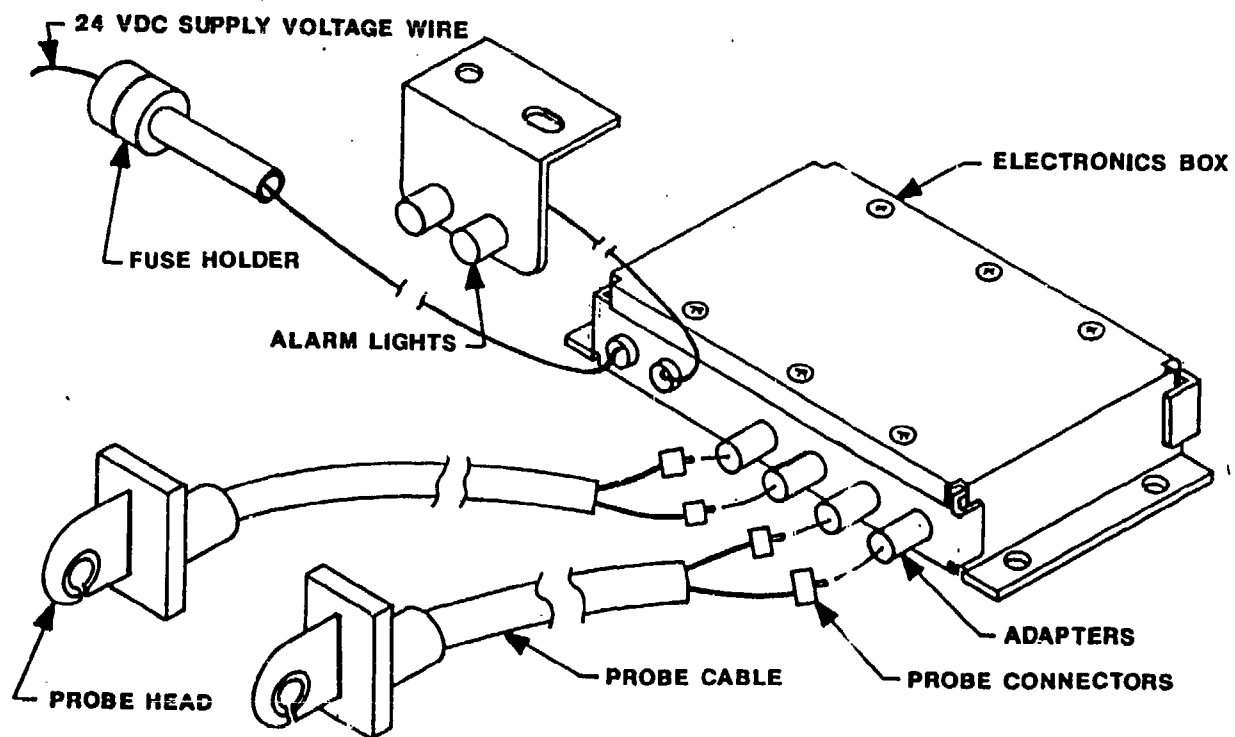


Figure 5-2. Dust Detector Components

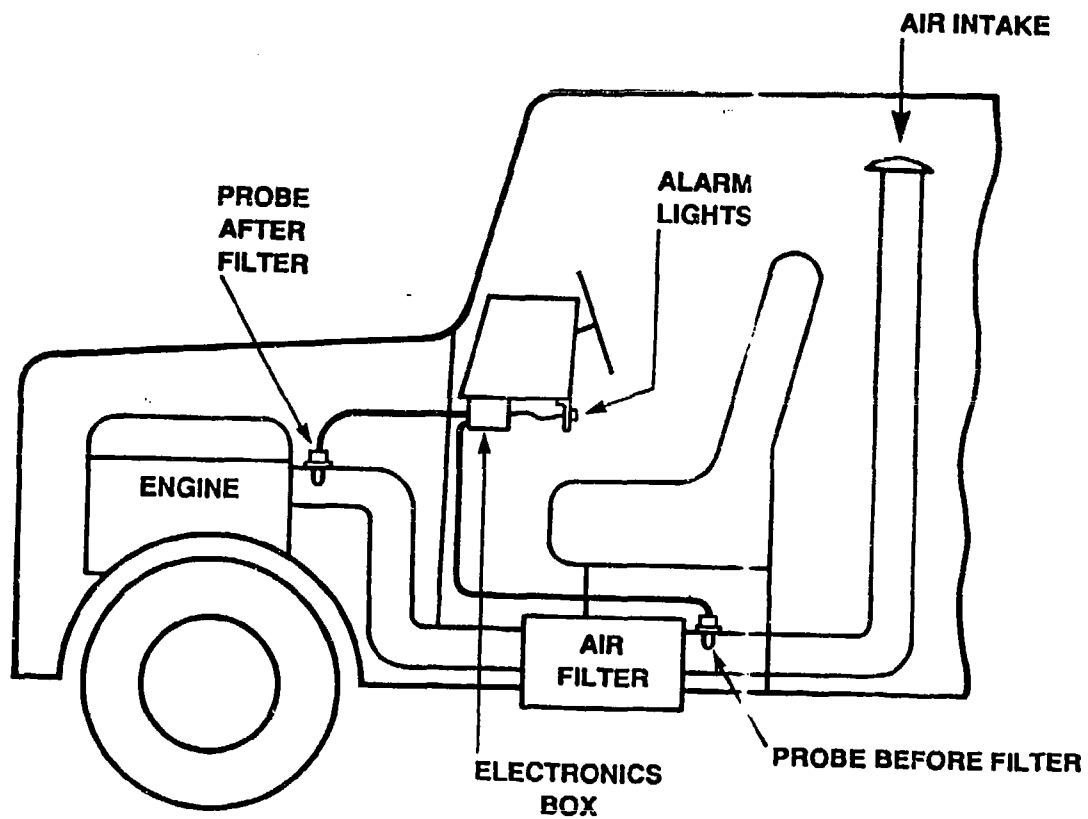


Figure 5-3. Dust Dectector Installation

adjusted at the factory. The current trigger levels are 20,000 particles/ft³ for concentration after the filter, and 98.2% for efficiency. Experience or further testing may show these trigger levels have to be changed. As an insurance against false triggering, the electronics requires that the concentration (or efficiency) be above the trigger for two consecutive time periods before an alarm light is turned on. This prevents the light from coming on for only a momentary burst of dust.

5.3.4. Self-Diagnostics. The dust detector has two self-diagnostic features to inform the driver that it is working properly. The first is based on the fact that there is always a continuous amount of light going through the probe. Therefore, if anything decreases this light below an acceptable level, the dust detector will know it. This could happen by the cable being cut, a probe connector coming loose, the optics getting too dirty, or an electronic component failing. If any of these happens, the alarm lights will flash off and on repeatedly, once each second. This can be distinguished from an actual high dust condition, because the lights flash on and off in a regular pattern. The second diagnostic feature is that the alarm lights always come on for about 2 seconds whenever the dust detector is first powered up. This allows one to see that the dust detector still has power, and its bulbs are not burnt out.

5.3.5. Calibration. One of the useful features of the dust detector is that it maintains its calibration. This is because the calibration is based on the physical dimensions of the air gap in the probe head. Since these dimensions will not change, recalibration should not be needed. For this same reason, the instrument does not need calibration when first built, because the physical dimensions can be made the same for each unit. This significantly reduces the production cost. Because of the probe's design, dirt on the optics does not affect the calibration. If the optics gets too dirty, there will not be enough light for it to operate. In this case, the alarm lights will flash on and off, as described in the previous paragraph.

5.3.6. Maintenance. The dust detector needs no regular preventative maintenance. As stated in the previous paragraph, it needs no recalibration. The only maintenance required is if the optics were to get dirty. As discussed later, tests have shown that the optics resist getting dirty. Experience will show how quickly they do get dirty with actual field use. However, once they do get dirty, the alarm lights will flash on and off to signal they need cleaning. Therefore, the dust detector can be left alone until the alarm lights signal otherwise.

5.3.7. Response Time. As soon as the dust detector senses high dust concentrations, it turns the alarm lights on immediately. The only limitation is when it is measuring efficiency, and the outside concentration (concentration before the filter) is very low. In this case, the concentration after the filter will be even lower. Therefore, the dust detector must wait a long time for enough particles to get a meaningful sample. In this case, the response time would be minutes instead of seconds. This is not a problem, because there is less risk of engine damage due to the low concentrations.

5.3.8. Pressure Measurement. During the course of this contract, the idea of using the dust detector to measure filter pressure drop was explored. It was found that this could be done, and it would add very little to the cost of the dust detector. A pressure tap hole could be added to the probe head in the duct. A hose could be run up the probe cable, which would then go to a simple pressure transducer in the electronics box. This would allow the vehicle's computer to continuously read the air filter pressure drop from the dust detector. Or, an additional alarm light could be added to the dust detector which would come on if the pressure drop exceeded a threshold. Since there is already a probe and electronics box, the advantage is getting a pressure measurement by adding only a

few inexpensive parts. The 10 dust detectors sent to TACOM did not have this pressure option.

5.4. Environmental Testing

5.4.1. Temperature. The electronics box was tested over the range of -25 F to +120 F. It was tested for correct operation and accuracy drift and passed successfully. The probe was tested over the range of -25 F to +300 F. It was tested for correct operation, accuracy and physical degradation. The probe passed successfully, proving that it can be installed in a hot engine compartment. Testing also showed that the probe can withstand intermittent temperatures of up to +350 F.

5.4.2. Shock and Vibration. The dust detector was subjected to shock and vibration testing. The shock and vibration levels were specified in the contract as those typical for combat and tactical vehicles. These levels are shown in tables 5-1 and 5-2. An operational test was performed during vibration, by passing particles through probe. When the particle concentration was above the trigger level, the alarm light would come on, as expected. Areas looked at during the testing were correct operation, structural integrity, and false triggering (alarm coming when it shouldn't). The dust detector passed all the tests successfully, showing it should operate in the rugged vehicle environment.

Table 5-1 Shock Test Parameters

<u>Type</u>	<u>Level</u>	<u>Duration</u>	<u>Number</u>
Basic Shock	40±4.8g	18±8.02 ms	3 per axis (18 total)
Gun Firing Shock	55±5.5g	2.5±0.02 ms	3 per axis (18 total)
Operational Shock	55±5.5g	0.5±0.1 ms	3 per axis (18 total)
Non-Destructive Ballistic Shock			
Latitudinal Axis	200±20g	0.5±0.1 ms	3 ea direction (6 total)
Vertical Axis	200±20g	0.5±0.1 ms	3 ea direction (6 total)
Longitudinal Axis	550±55g	0.5±0.1 ms	3 ea direction (6 total)

Table 5-2 Vibration Test Parameters*

<u>Axis</u>	<u>Frequency</u>	<u>Level</u>
Vertical	5 to 25 HZ	1 g
	25 to 57 HZ	0.030 inch D.A.
	57 to 500 HZ	5 g
Lateral and Longitudinal	5 to 25 HZ	1 g
	25 to 44 HZ	0.030 inch D.A.
	44 to 500 HZ	3 g

- * Vibrations applied at logarithmic sweep rate of 20 minutes per sweep cycle followed by 20 minute dwells at each resonant frequency. Total time was 120 minutes per axis. Conditions of Specification MIL-STD-810, Method 514.1 were used.

5.4.3. Electromagnetic Interference (EMI). The dust detector underwent EMI testing. Emissions radiated and conducted from the dust detector to the outside environment were measured. Acceptable levels were specified in the contract, and the dust detector's emissions were well below the allowable levels. In addition, the dust detector was tested for susceptibility to radiated and conducted noise, using levels typical for this type of instrument. Again, the dust detector passed the tests and proved sufficiently immune to outside interference. The dust detector was also tested to see if it met MIL-STD 1275 for power supply switching transients as required in the contract. The dust detector passed this test successfully. The tests applied are listed in table 5-3. The specific numbers for these tests are detailed in the listed military standards. In all these tests, the areas looked at were correct operation and false triggering.

Table 5-3 Electromagnetic Interference Test Parameters

<u>Military Standard</u>	<u>Test Number</u>	<u>Description</u>
MIL-STD 461A, Notice 4	CE07	Conducted Emissions
	CE04	Conducted Emissions
	RE02	Radiated Emissions
	RE05	Radiated Emissions
	RS02	Radiated Susceptibility
MIL-STD 1275	--	Conducted Susceptibility
	--	Switching Transients

5.4.4. Field Testing.

5.4.4.1. General. Dust detectors with only one probe were used for all the field testing. This is because the dust detector was originally designed with one probe, to be placed after the filter to measure only concentration. It was the field testing that showed the need for two probes, so efficiency could be measured. A dust detector was installed on an army 5-ton dump truck at Fort Snelling, Minneapolis, and operated on the running vehicle. Liquid particles were introduced into the air-intake duct after the filter to simulate road dust. When the concentration of the liquid particles was increased above the trigger level, the alarm light came on.

5.4.4.2. Yuma Proving Grounds Testing. Additional field testing was done by installing three dust detectors on a single 5-ton truck at Yuma, Arizona proving grounds. One probe was put before the filter to measure outdoor concentration coming into the filter. A second probe was put after the filter, but before the turbo charger. A third probe was put after the turbo charger. The truck was driven over a variety of terrains to simulate different outdoor dust levels. During all these tests, the dust detector operated correctly, with no false triggering. The probe before the turbo charger detected many more particles than the one after, probably because many particles are lost in the turbo charger through impaction.

5.4.4.3. Concentration Versus Efficiency. During the Yuma field testing, it was observed that the concentration after the filter depended directly on the outside concentration. For example, when the concentration coming into the filter doubled, the concentration measured after the filter also doubled. Therefore, we found it difficult to identify one specific concentration level after the filter, which indicates a leak. The units installed at Yuma had their trigger level set at 20,000 particles/ft³ (particles > 7 micron). While driving behind another vehicle throwing up dust, the concentration after the filter exceeded this threshold, even though the air filter was good. Next, we drove on the asphalt highway, and the concentration measured by the dust detector before the filter

was less than the threshold. So, on the asphalt, the dust detector after the filter would never have triggered, even if the air filter were removed. TSI concluded that, because of the wide range of possible outdoor concentrations, there is no one trigger level for concentration after the filter that will always indicate if the filter is bad. Because of these field testing results, the dust detector was modified to measure filter efficiency, which is independent of outdoor concentration. The drawback with having to measure efficiency is that two probes are needed, one before and one after the filter.

5.4.5. Calibration Testing. To establish the calibration of the dust detector, two tests were done. First, particles all of the same size were passed through the probe. These particles were generated with a TSI Vibrating Orifice Aerosol Generator (Model 3450). This tested the dust detectors ability to count particles only above a certain size. Secondly, Arizona fine road dust was passed through the probe. A TSI Aerodynamic Particle Sizer (Model 3310) was used as a calibration standard to measure the concentration of particles above a certain diameter. This tested the dust detector's ability to measure concentration accurately. Using this same test setup, large concentrations of dust were continuously passed through the probe for an extended period of time. This was a kind of accelerated life test to see how quickly the probe's optics would get dirty. This test showed that because of the probe's design, the optics are very slow to get dirty.

ADDENDUM

OPERATION AND INSTALLATION MANUAL

DUST DETECTOR

Operation and Installation Manual

October 1990

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About this manual

The Dust Detector Operation and Installation Manual describes how to install, operate and maintain a dust detector.

- Chapter I describes how to install the dust detector on any vehicle.
- Chapter II explains the dust detector's daily operation and the function of its alarms.
- Chapter III describes the dust detector's parts and functions in detail.
- Chapter IV lists what maintenance procedures are needed.
- Chapter V contains troubleshooting procedures.
- The Appendix contains specifications.

Introduction

The dust detector is used to measure the performance of a vehicle's air cleaning system. It does this by measuring the concentration of airborne dust before and after the air cleaner. The instrument has probes which are mounted directly in the air flow so dust concentration is measured continuously. When dust levels after the air cleaner go above unacceptable levels, the driver is alerted by an alarm within seconds.

I

Installation

The following is a list of the parts supplied with each dust detector; if any are missing or damaged, notify TSI immediately.

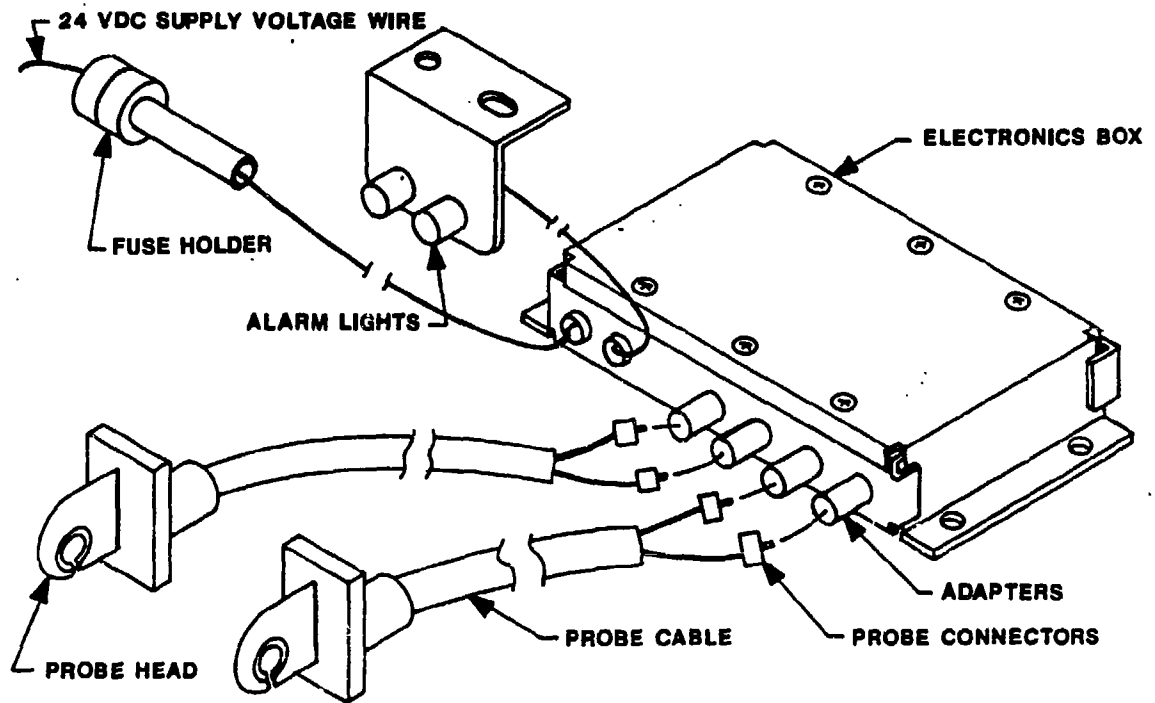
Unpacking	Description	Quantity
	Electronics box	1
	Probe	2
	Hose clamp mounting adapter	2
	Alarm light bulb (extra)	1
	Fuse (extra)	1
	Mounting screw self tapping (electronics box/alarm bracket)	6
	Mounting washer (electronics box/alarm bracket)	6
	Probe mounting screw	4
	Probe gasket (extra)	2
	Operation and Installation Manual	1

The dust detector components are shown in figure 1. These components are described in more detail in Chapter III (DESCRIPTIONS OF PARTS AND FUNCTIONS). The dust detector has two main components, these are the electronics box and the probes. The electronics box, with its alarm lights, are installed in the drivers compartment. The probes go from the electronics box to air intake ducts before and after the filter. Figure 2 shows an example of a dust detector installation on a truck.

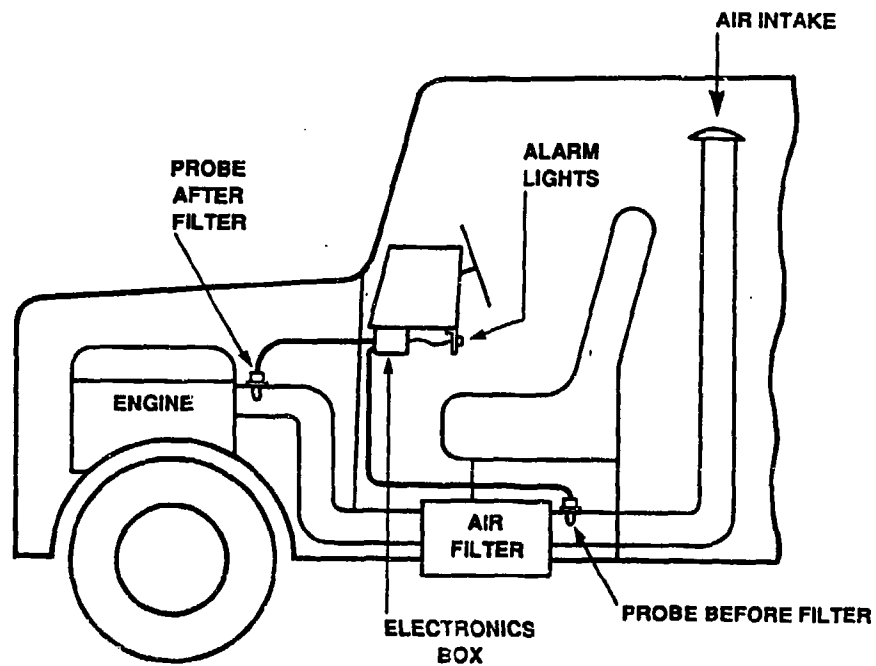
Installing the dust detector

The following paragraphs explain how to install a dust detector on a vehicle.

NOTE: The electronics box has four red protective covers on its adapters. The probes each have two black protective caps screwed onto the probe connectors. Do not remove these protective coverings until right before you screw the probe connectors into the electronic box adapters.



**DUST DETECTOR COMPONENTS
FIGURE 1**



**EXAMPLE OF DUST DETECTOR INSTALLATION
FIGURE 2**

Electronics Box

The electronics box should be mounted in an out of the way place in the vehicle's operator or driver compartment. It must be close enough to the air cleaner system so the probe cables can reach the air intake ducts.

WARNING: DO NOT mount the electronics box in the engine compartment where it can be exposed to excessive heat. DO NOT mount it on the outside of the vehicle where it can be exposed to precipitation, mud, slush, etc.

The metal electronics box is used for the electrical ground path, therefore, it must be securely mounted to a grounded metal portion of the vehicle. Mount the box to a flat metal surface using the four holes on the boxes flanges. Use star washers such as the ones provided to obtain a good electrical connection.

The supply voltage wire is the red heavy gauge wire with the black in-line fuse holder. This wire should be permanently connected to the vehicle's 24 volt DC power. It should be connected so that the dust detector is always powered when the vehicle is running, but it is not powered when the vehicle is off. It doesn't need to be connected to a fused line since the dust detector has its own in-line fuse.

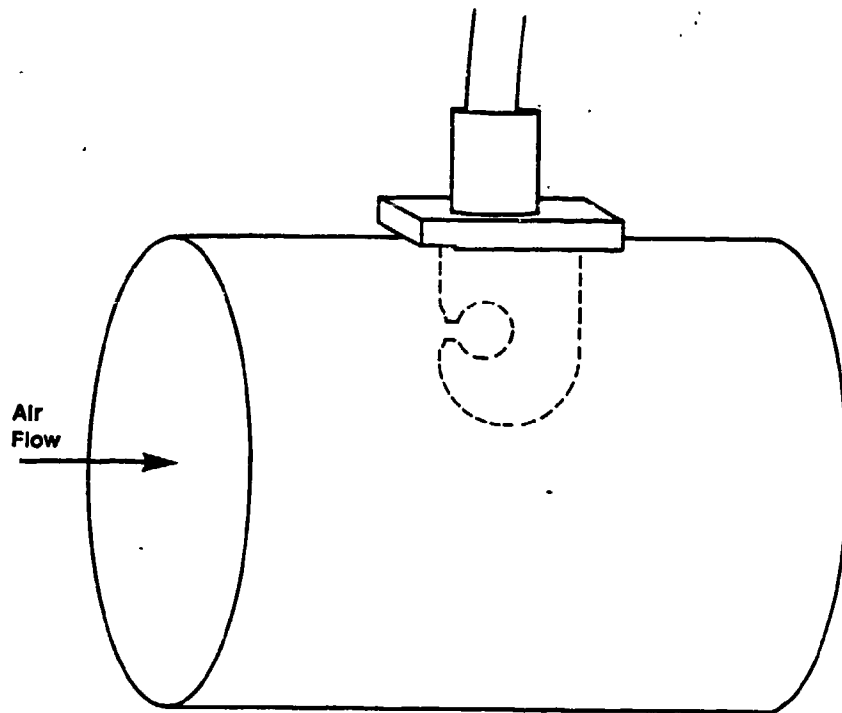
Alarm Lights

If red alarm lights are included, they will be on a separate cable with their own bracket. This bracket should be mounted with the two screws and washers provided so the driver can easily see the lights. The bracket does not have to be electrically grounded.

For installation of one of the other two alarm methods (ones without alarm lights) contact TSI for special instructions.

Probe Heads

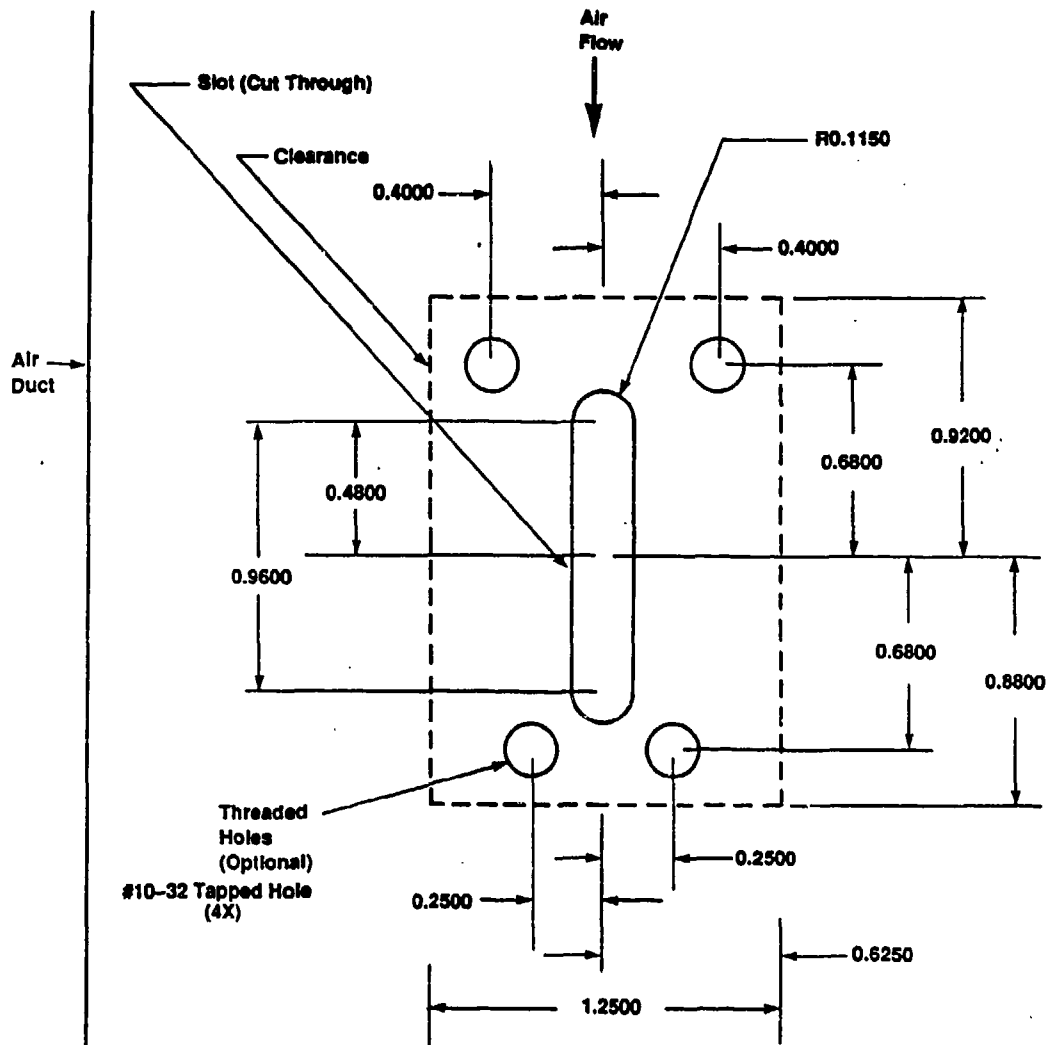
The two probes will be installed in two places in the air intake ducting. One must be before the air cleaning system. The other must be after the air cleaning system, preferably as close to the engine as possible. The probes are interchangeable so the one with the longer cable can be installed before or after the filter depending on where it is needed. Figure 3 shows the probe head installed in a duct. Note the orientation of the probe with respect to the air flow.



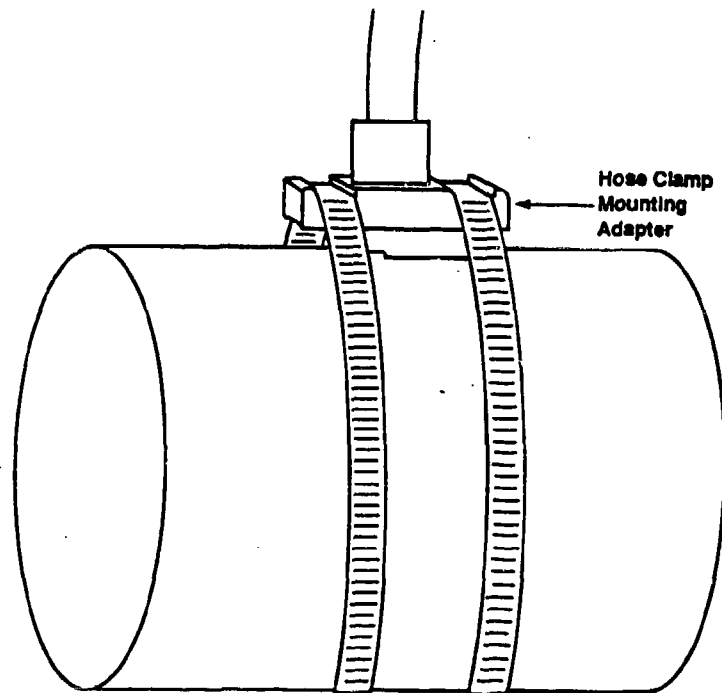
PROBE HEAD MOUNTING

FIGURE 3

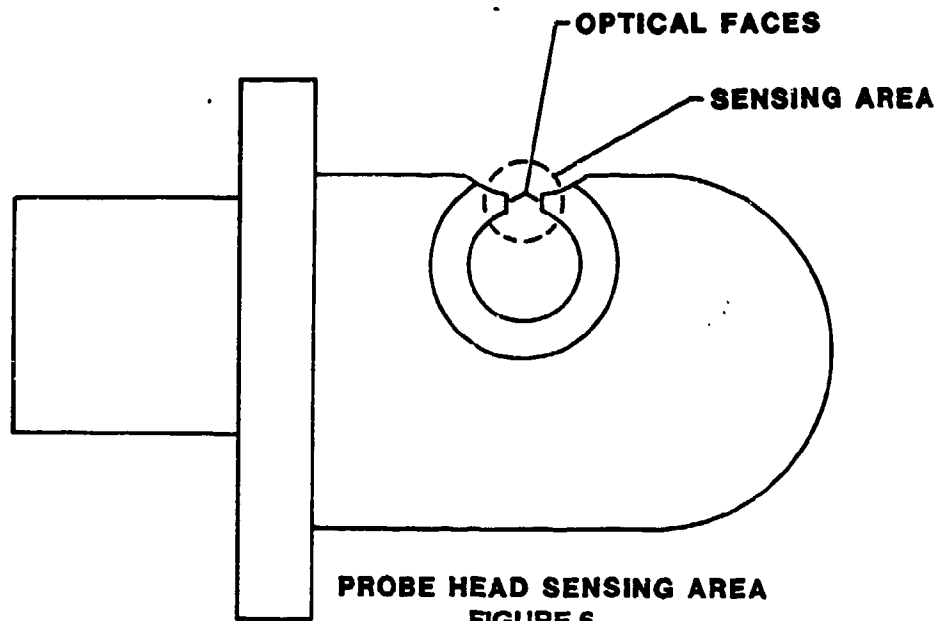
A slot must be cut in the piece of ducting where the probe is to be mounted. Figure 4 gives the mounting hole pattern dimensions. Again note how the probe is oriented with respect to the air flow. The probe can be secured to the duct in two ways. One is by making threaded holes in the duct as shown in figure 4. The probe is then mounted using the 4 screws provided. If threaded holes are not possible, the probe can be held down by two large hose clamps as shown in figure 5. If hose clamps are used, slip the supplied hose clamp mounting adapter over the top of the probe head. This will keep the hose clamps from sliding off. If hose clamps are used, extra care must be used to insure the probe head is orientated correctly as shown in figure 3. The probe head sensing area is shown in figure 6. This must point into the flow. When mounting the probe head make sure the supplied gasket is still on the probe head's flange.



PROBE HEAD MOUNTING HOLE DIMENSIONS
FIGURE 4



PROBE HEAD MOUNTING BY HOSE CLAMPS
FIGURE 5



The probe's sensing area is within the small 1/10th inch gap in the probe head as shown in figure 6. Do not touch the probe in this area and avoid getting any debris into this area. This area contains optical glass fiber faces which have been polished and cleaned. Large amounts of dirt, oil or other contaminants on these faces from handling can seriously affect the instrument's performance.

Probe Cable

Once the probe head has been mounted, route its cable back to the electronics box. The cable must be secured along its length with tie wraps or other means. It cannot be left to flop loosely against other parts of the vehicle.

CAUTION: Do not route the cables close to any very hot parts such as the exhaust manifold. The cables outer jacketing will melt at temperatures above 350°F.

CAUTION: The probe's cable contains glass optical fibers, therefore, the cable cannot be bent sharply when handling or mounting or the fibers will break. The minimum allowed bend radius is about one inch. In addition, do not crush the cable with excessive clamping force.

Probe Connectors

Once the two cables are routed to the electronics box, they can be attached to the box. Unscrew the black plastic protective covers from the probe connectors. Remove the red plastic caps which are over the adapters on the electronics box. Do not remove any of these protective coverings before this time. The ends of the probe's connectors have a delicate, polished glass fiber face. Do not touch these ends or allow them to get scratched or dirty. In addition, do not allow any dirt or liquid to get down inside the four adapters on the electronics box. Screw the four connectors into the four adapters.

The connectors from the probe before the filter go into the two adapters marked "before filter". The two connectors are interchangeable so it doesn't matter which connector goes into which of the two adapters. The two connectors from the probe after the filter go into the two adapters marked "after filter". Again it doesn't matter which one goes where, as long as they are both in the two adapters marked "after filter". Tighten them as far as you can by hand, then use a pliers and tighten them an additional 1/8 turn maximum.

CAUTION: Do not over tighten the connectors or they will be damaged.

II Operation

Operator Input

The dust detector does not require operator input during normal use. Whenever the vehicle is running the dust detector is continually measuring filter performance. If there is a fault condition, the alarms will notify the vehicle operator. There are two alarm conditions, one indicates poor filter efficiency and the other indicates high dust concentration after the filter.

**Power On
Light**

When the dust detector is first powered up (vehicle is turned on) the alarm lights should come on for a couple of seconds. This is to show that the dust detector has power, its circuits are working normally, and the alarm lights haven't burnt out. If one or both alarm lights are not illuminated for a few seconds when the vehicle is turned on, there is a problem with the detector. Please see the Troubleshooting Section for further detail.

Alarm Lights

Once the vehicle is started, the alarm lights will not come on during normal driving until there is a fault condition. If either light comes on (except when vehicle is first started), this means there is a fault condition with the air cleaning system or possibly the dust detector. See chapter III (Description of Parts and Functions) for a detailed description of what the lights are indicating when they come on.

III

Description of Parts and Functions

The main components of the dust detector are the electronics box and the two probes (see figure 1).

Electronics Box

The electronics box contains all of the electronics parts. This box has a single wire coming out for the supply voltage. This wire has an in-line fuse holder. The fuse is supplied by TSI. There are also alarm lights on their own mounting bracket attached to the electronics box by a cable. Finally there are four adapters for attaching the probes.

Probes

The two probes are identical except possibly their length in some cases. On one end of each probe is a probe head which mounts in the air intake duct. The probe cables contain glass optical fibers which carry light to and from the probe head. The fiber optic probe connectors on the other end of the probe screw into the adapters on the electronics box.

What Is Measured

The dust detector measures two separate aspects of the air cleaning system. The first aspect is filter efficiency. Filter efficiency is defined as

$$\text{Efficiency} = 100 \times \left(1 - \frac{C_a}{C_b} \right)$$

Where: C_a = Dust concentration after filter
 C_b = Dust concentration before filter

For example, an efficiency of 99% means that 1% of the dust going into the filter gets through it. The concentration of dust before and after the filter is measured and compared to get filter efficiency. When the efficiency falls below a factory set trigger level, an alarm is generated.

The second aspect measured is concentration of dust after the filter. When this concentration goes above a factory set trigger level, an alarm is generated. Both of the trigger levels are set within the electronics box at the factory.

Alarm Outputs

An alarm can be generated in three different forms. The standard method is with a pair of red alarm lights. These are attached to the electronics box by a cable and have their own mounting bracket. In the second method a vehicle's computer can electronically read in the alarm signal through wires running to the dust detector's electronics box. In the third method the dust detector provides contacts which can be used to enable some other type of device or alarm. The dust detector comes from the factory already set up for one these three alarm methods.

Leak Light

The alarm for poor filter efficiency is labeled "LEAK" on the alarm light bracket. When this light comes on it means the filter is allowing a larger than normal amount of dust to get to the engine. This means there is a fault within the air cleaner system and the engine is in danger of being ruined. The light may flash on for very brief periods of time, or it may stay on for a long time.

Dust Level Light

The alarm for high dust concentration after the filter is labeled "DUST LEVEL". When this light comes on it means there is an excessively high level of dust getting into the engine. The engine is in danger of being ruined. This can be the result of a leak in the filter, or it can be caused by very high dust levels outside, even though the filter is working properly. Like the other light, this light may flash on for very brief periods of time, or it may stay on for a long time.

Both the leak and dust level lights may be on at the same time, or only one or the other may be on at a time. One may be flashing off and on irregularly while the other is on continually. This is because the two lights are indicating two independent conditions.

Resetting Alarm Lights

Once the problem has been corrected the light may go off depending on the conditions. The dust detector measures dust over a period that can vary from less than a second to several minutes. The higher the dust concentrations it is measuring, the shorter this measurement period will be. After each measurement period the alarm light is turned on or off depending on what was measured and the trigger level. Once the light is turned on, it stays on at least until the end of another measurement period. After the next period it may stay on or turn off depending on whether the dust levels have changed. Therefore, if the next measurement period takes several minutes (which happens when the probes are seeing very low dust levels) the alarm light will stay on even though the initial cause may be removed. However, if there are higher dust levels going into the filter, the measurement period is shorter and the light will turn off sooner. Once the dust detector is powered off any alarm conditions are forgotten by the dust detector. When the dust detector is powered back on the alarm lights will stay off (except for a couple seconds at power on) provided the cause has been removed.

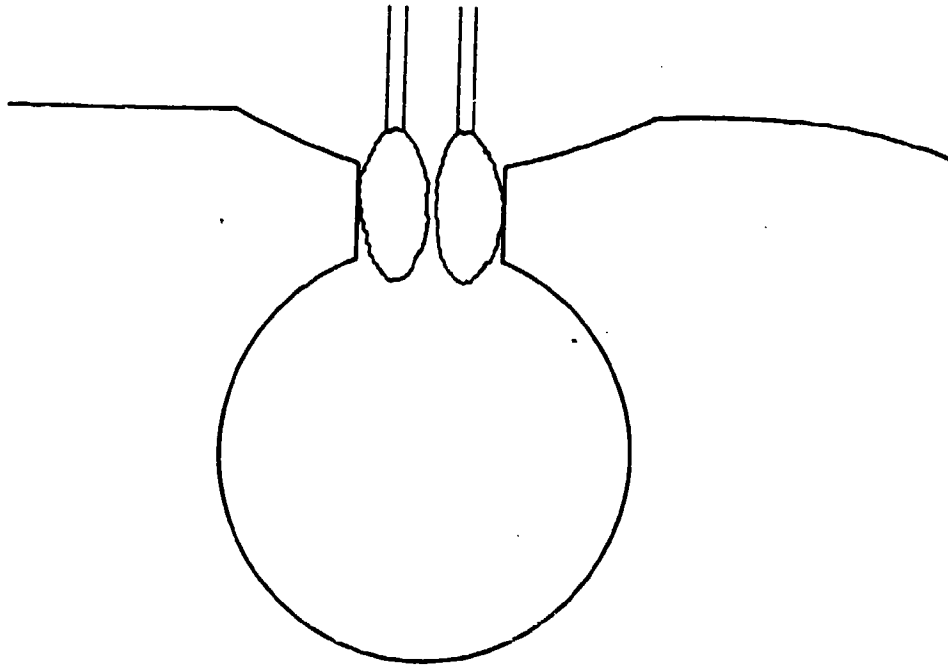
Diagnostic Alarm

An additional reason why the alarm lights may come on has to do with a self diagnostic feature of the dust detector. The amount of light being transmitted through the optical fibers of both of the probes is continually being monitored by the dust detector electronics. If a problem with the probes is detected, the dust detector will continually flash both lights on and off for about 1 second periods. They will both be on 1 second, then off 1 second, then on 1 second, etc. This regular pattern of on and off flashing can be easily distinguished from an air cleaner fault. With an air cleaner fault one or the other or both lights will flash on with an irregular pattern or will just stay on. If both lights flash on and off with a regular 1 second frequency, this means there is something wrong with the dust detector. See the Troubleshooting section for what to do if this happens.

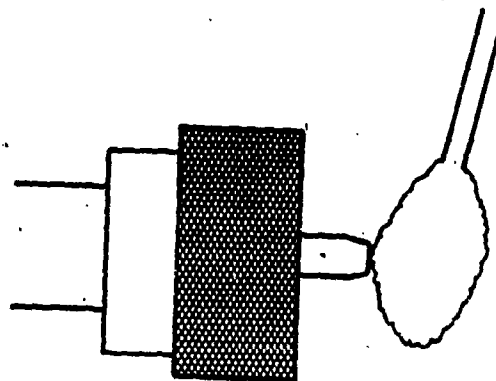
IV Maintenance

The dust detector needs no regular maintenance. The instrument design is such that it will not go out of calibration so no re-calibration is needed. Over time it is possible for the optical faces on the probe heads to get dirty. When they get too dirty the alarm lights will flash regularly on and off every second as described in chapter III (Description of Parts and Functions) under diagnostic alarm. The optical faces don't need to be cleaned until the alarm lights indicate in this way that it is needed. If the optical faces need cleaning see the Troubleshooting section for a description of how to clean the faces.

Figure 7 shows how to clean the optical faces in the probe head if the diagnostic alarm indicates it is needed. Figure 8 shows how to clean the probe connectors as described in the troubleshooting section. The probe connectors may get dirty from handling, but will not get dirty once they are installed.



**CLEANING PROBE HEAD OPTICAL FACES
FIGURE 7**



CLEANING PROBE CONNECTORS
FIGURE 8

V

Troubleshooting

Symptom	Possible Causes	Solution
The alarm lights flash on and off regularly once a second.	The probe cable has been cut, damaged or bent too tightly, which has broken one of the optical fibers inside the probe cable.	Replace with a new probe.
	The probe connectors are not tightly screwed onto the electronics box.	Check the four probe connectors going into the back of the electronics box. If one is loose, hand tighten it and tighten an additional 1/8 turn maximum with a pliers CAUTION: DO NOT over tighten the connectors or they will be damaged.
	The optical faces on the probe head have gotten dirty (see Figure 6).	Remove both probe heads from duct. Clean the faces on both sides of the sensing gap as shown in Figure 7. Use some type of alcohol and either a Q-tip or other clean, soft cloth. After cleaning, wipe the faces with a dry piece of the same material. CAUTION: DO NOT use any abrasive or dirty material to clean the faces.
	The ends of the fiber optic connectors on the probe are dirty from handling.	Unscrew the 4 connectors from the back of the electronics box. Clean the ends of the connectors as shown in figure 8. Use some type of alcohol and either a Q-tip or other clean, soft cloth. After cleaning wipe the connector ends with a dry piece of the same material to clean the faces.
	A component inside the electronics box has failed.	Replace the electronics box.

Symptom	Possible Causes	Solution
The alarm light(s) don't come on when the vehicle is first started.	The electronics box is not correctly connected to 24 volt DC power source.	Verify the connection of the input power wire (the one with the black in-line fuse holder.) Insure that it is connected to the vehicle's 24 volt DC power when the vehicle is running. Also verify that the electronics box is making a good ground connection to the vehicle's chassis ground.
	The alarm bulb is burnt out.	Replace with bulb supplied by TSI. Twist the red plastic alarm light lens counter-clockwise a few degrees. Then pull it off to expose the bulb. Pull the bulb straight out without twisting.
	The fuse has blown.	Replace with 1 amp slow-blow fuse.
	A component inside the electronics box has failed.	Replace the electronics box.

Appendix A

Specifications

Filter efficiency alarm levels:

Efficiency	66.7% to 99.985% (customer specified)
Penetration	33.3% to .015% (customer specified)

High Particle Concentration alarm levels:	100 to 10,000,000 particle/ft ³ (customer specified)
--	---

Outputs:

Filter Efficiency Alarm:	light indicator, or 1 to 13 volt logic level, or 600 mA, 40 VDC contact (customer specified)
--------------------------	---

High Particle Concentration Alarm:	light indicator, or 1 to 13 volt logic level, or 600 mA, 40 VDC contact (customer specified)
---------------------------------------	---

Particle Detection Efficiency:	50% at 7.8 μ m 90% at 16 μ m
--------------------------------	---

Response time: (filter efficiency and high concentration alarms)

$$\text{Response time (seconds)} \propto \frac{1}{\frac{\text{downstream conc. (part./ft}^3\text{)}}{16,000}}$$

Example: response time = 1 sec. at dust concentration = 16,000

Air flow velocity range: 200 to 10,000 feet/minute

Operating Temperature:

Electronics -	-40 to 185°F (-40° to 85°C)
Probe (continuous)	-40 to 300°F (-40° to 150°C)
Probe (intermittant)	-40 to 350°F (-40° to 175°C)

Probe Cable: 1-25 ft. standard (longer lengths are available on request), 3/8 inch diameter

Power Requirements: 16-30 VDC, 200 mA continuous plus 80 mA per alarm light when lit.

Dimensions (electronics box): 6 3/4 x 4 x 1 1/4 inches

Complies with following specifications: MIL STD 461A notice 4 (CE 07, CE 04, RE 05, RE 02, RS 03); MIL STD 1275A; MIL STD 810 Method 514.1

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Mawby, Patricia

From: Margrif, Frank [MargrifF@tacom.army.mil]
Sent: Wednesday, May 09, 2001 3:00 PM
To: 'pmawby@dtic.mil'
Subject: FW: Distribution Statement Change for Two (2) TARDEC Technical Re ports

Pat: I tried to forward this message to Larry Downing but got a message back address unknown, fatal error. Obviously something went wrong. Could you please check this out. I would appreciate it. I used the e-mail address you gave me. Maybe you could forward it to him.

Frank

-----Original Message-----

From: Margrif, Frank
Sent: Wednesday, May 09, 2001 2:12 PM
To: 'ldowning@dtic.mil'
Cc: Raffa, Charles; Mushenski, Mark 'WGM'; Kuhn, David
Subject: FW: Distribution Statement Change for Two (2) TARDEC Technical Re ports

Mr. Larry Downing:

As explained in the two messages sent below, we are requesting that the Distribution Statement on these two (2) reports be changed to: "DISTRIBUTION STATEMENT A: APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED". In this way potential contractor hopefully will be able to get copies of the reports if they need too through your office.

I sent through the mail last Friday (6 May) one (1) copy of each report to Pat with the changed Distribution Statement. However, Pat informed me in her last message that she found both reports in the database with the appropriate AD numbers. Thus, your reports need to be updated to new distribution statement.

Our legal office at TACOM informed me that the project engineer can decide when the reports can have the Distribution Statement changed. I and another engineer Mr. Mark Mushenski are considered the project engineers on these reports and we have both agreed that the Distribution Statement should be changed to "A".

Hope this can be accomplished and meets with your approval.

Thanks for your effort in this matter. Please contact or reply to me if there are any questions.

Frank Margrif
Propulsion Product Support Team
Research Business Center
Comm (810) 574-5796
DSN 786-5796
FAX -5054

-----Original Message-----

From: Raffa, Charles
Sent: Wednesday, May 09, 2001 10:26 AM
To: Margrif, Frank
Cc: Mushenski, Mark 'WGM'
Subject: FW: Distribution Statement Change for Two (2) TARDEC Technical

Re ports

-----Original Message-----

From: Mawby, Patricia [mailto:PMawby@DTIC.MIL]
Sent: Tuesday, May 08, 2001 7:51 AM
To: 'Raffa, Charles'
Subject: RE: Distribution Statement Change for Two (2) TARDEC Technical
Re ports

Charles,

I found both of your reports in the database. DTIC has DAAE07-89-C-R011, Phase II, with our AD number as ADB159687 and your March 1991 as ADB159757. If you only need the distribution changes a letter to our Security Officer should be OK. His name is Larry Downing, (703) 767-0011 and his email is: ldowning@dtic.mil. If you have any questions, please call. If we looked before, I don't know why they weren't found. Again, I hope this hasn't caused you any problems.

Pat
(703) 767-9038

-----Original Message-----

From: Raffa, Charles [mailto:RaffaC@tacom.army.mil]
Sent: Monday, May 07, 2001 5:30 PM
To: 'Pmawby@dtic.mil'
Cc: Kuhn, David; Mushenski, Mark 'WGM'; Margrif, Frank
Subject: FW: Distribution Statement Change for Two (2) TARDEC Technical
Re ports

> -----Original Message-----

> From: Margrif, Frank
> Sent: Friday, May 04, 2001 1:15 PM
> To: Daniska, Lyn
> Subject: Distribution Statement Change for Two (2) TARDEC Technical
> Reports
>
> Lyn; Could you put Charlie's title on and let him send this out to Pat.
> Her e-mail is pmawby@dtic.mil. Also send copy to David Kuhn and Mark
> Mushenski.
>
> Thanks ,Frank
>
> 06 May 01
>
>
>
>
> Ms. Pat Mawby;
>
> Two (2) Technical Reports from TACOM/TARDEC were published over ten (10)
> years ago containing Distribution Statements either B or C which limited
> their distribution. The title of reports are as follows: (1) ENGINE INTAKE
> AIR DUST DETECTOR (U), (PHASE II), CONTRACT NUMBER DAAE07-89-C-R011,
> NOVEMBER 1990, (2) ENGINE INTAKE AIR DUST DETECTOR REQUIREMENTS AND

> PERFORMANCE, MARCH 1991.

>

> Per our discussion on 3 May 01, your office does not have a copy of either
> report. These reports need to become available for future contractors
> evaluation in helping them possibly prepare a Phase I SBIR proposal for a
> future dust detector for the new Abrams/Crusader engine. Therefore, the
> TARDEC project engineer has determined that both reports can be changed to
> a Distribution Statement A," approved for public release". We completed
> the distribution statement changes on each report and forward one (1)
> copy each to your office on 6 May 01.

>

> The POC for this action is Frank Margrif, tel:(810) 574-5796 or DSN
> 786-5796.

>

>

>

>

>

>

> CHARLES J. RAFFA

>

> Associate Director

>

> TACOM

>